

Methods for Incorporating Key Uncertainties into PM Risk Analyses

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NAS Report on EPA's $PM_{2.5}$ Benefits Analysis Methods

- Released September 2002.
- EPA needs to better integrate uncertainties into its primary risk estimates.
- Stressed importance of considering uncertainties in combination rather than as individual sensitivity analyses.

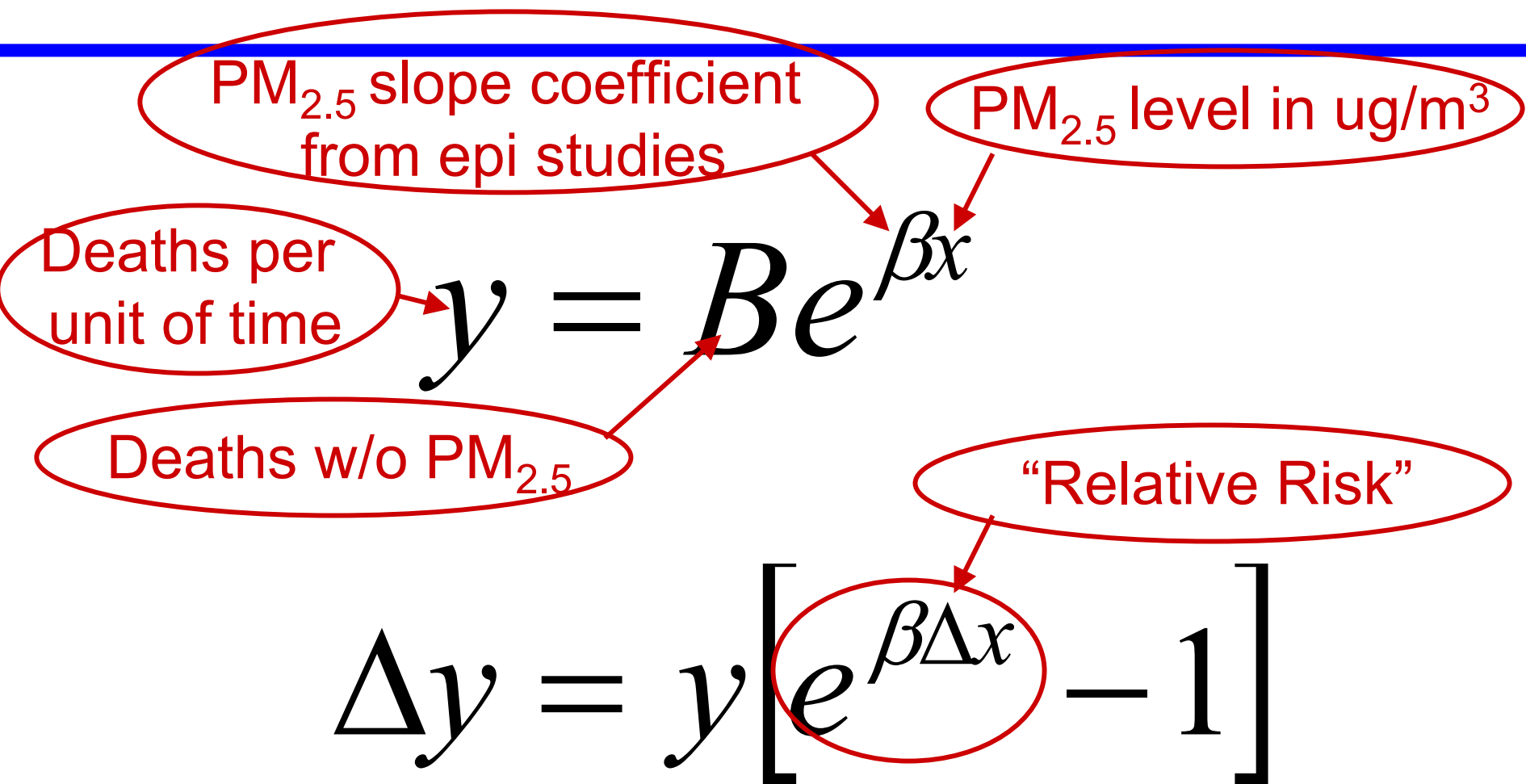
This Presentation

- **Review basic health risk analysis formula.**
- **Modifications to formula to incorporate:**
 - ◆ Acute vs. chronic risks
 - ◆ Nonlinearities (“thresholds”
 - ◆ Different relative potencies of PM_{2.5} constituents
 - ◆ Different implementation strategies
- **Illustration of interactions of these uncertainties on base risk estimates:**
 - ◆ Using Atlanta SEARCH project data
 - ◆ Applying Monte Carlo simulations

Key Points

- Complex uncertainties can be incorporated into a risk formula
 - ♦ while retaining consistency with epidemiological associations that did not address these uncertainties.
- They affect the base risk estimates substantially.
- There are substantial interactions in their impact on base estimates of risk.
 - ♦ *The combinations of uncertainties matter.*
- Acute vs. chronic risk is a key uncertainty and should not be assumed away.

The Basic Risk Analysis Formula



Acute and Chronic Risk Estimation

Chronic: β comes from a long-term epi study

x is an annual or longer average concentration
 B, y are annual mortality

Acute: β comes from a daily epi study

x is a 24-hour average concentration, x_i

Annual mortality requires a summation over all days:

$$y_m = \sum_{i=1}^{365} \frac{B}{365} e^{\beta_a x_i}$$

Which Is The Better Risk Estimate?

- **Only chronic studies can identify long-term effects.**
 - ◆ But they are subject to great statistical control concerns.
 - ◆ There is no scientific basis to accept or refute chronic effects.
- **Acute studies are inherently more controlled.**
 - ◆ Constant socio-economic conditions.
 - ◆ Stable PM constituent mix.
 - ◆ Stable associations between PM and other pollutants.
 - ◆ Remove potential biases from PM monitor placements.
 - ◆ Temporal stability in measurement of individual exposure.
 - ◆ Better ability to explore relative role of PM constituents.
 - ◆ There is no scientific basis to accept or refute acute effects.

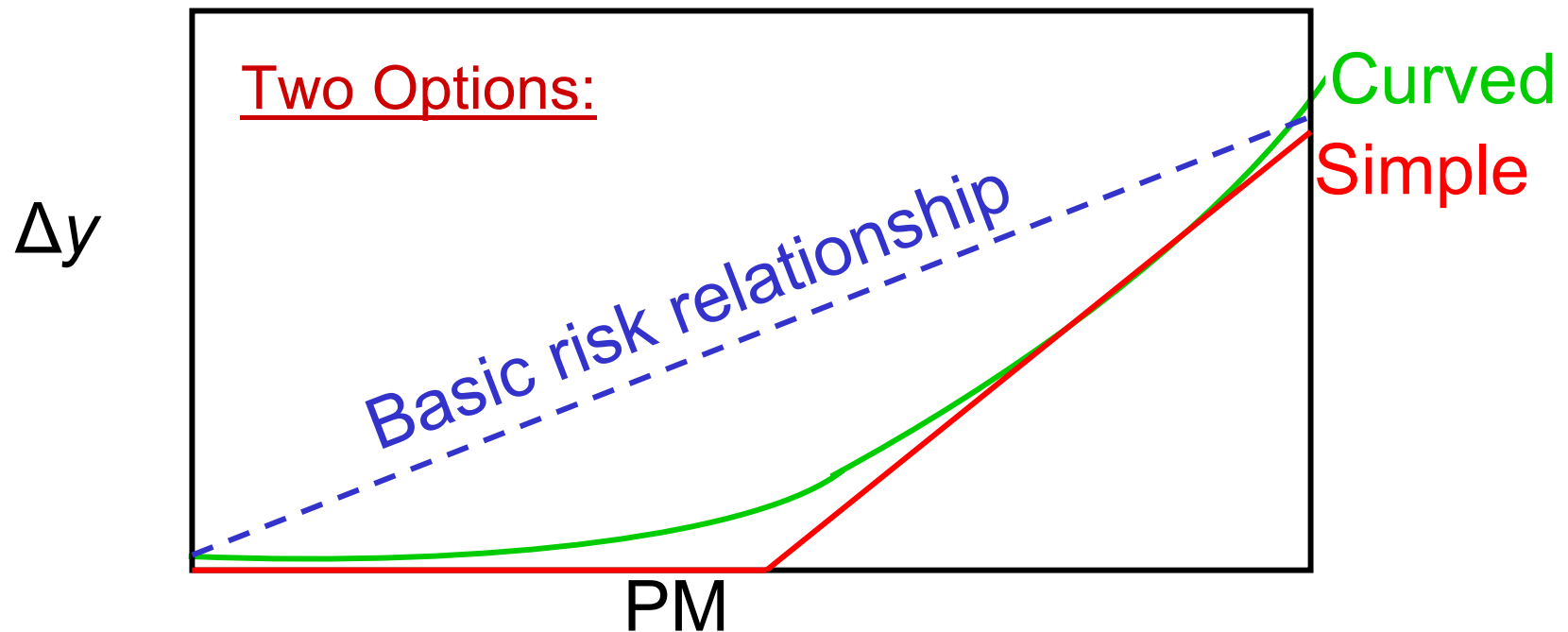
**If the choice significantly affects risk estimates,
this uncertainty should not be assumed away.**

The Challenge

**How can we extend the basic risk formula
while maintaining consistency with the
underlying epidemiological associations?**

Incorporating Nonlinearities

- Epi tools may be incapable of detecting.
- Principles of toxicology tell us it is probably there.



Incorporating Nonlinearities - Formulas

Simple:

$$y = Be^{\beta(x-t)} \text{ for } x < \text{threshold}, t$$
$$y = B \quad \text{for } x \geq t$$

and adjust β to preserve relative risk over range of observed PM

Curved:

$$y = B(1 + \alpha x^\gamma)$$

where: $\alpha = \theta \frac{(e^{\beta(m-t)} - 1)}{m^\gamma}$

where m = maximum observed PM value in epi data set.

θ and γ are tuning parameters that control of curve to remain between the simple threshold curve and the original curve, while preserving average slope over $[0, m]$.

Heterogeneous Constituent Potencies

- Widely recognized.
- Never before addressed in risk analysis.
- Relevant data slowly emerging.

Formula extension:

$$y = Be^{\beta x} = Be^{\beta(x_a + x_b + x_c)} = Be^{\beta x_a + \beta x_b + \beta x_c}$$

$$y = Be^{\beta_a x_a + \beta_b x_b + \beta_c x_c}$$

Select individual coefficients for constituents a , b , c so that they have desired potencies relative to each other, yet still average original single coefficient from epi study.

Heterogeneous Constituent Potencies

-- An Example of the Calibration

- Constituent *a* is to be given twice the potency of constituents *b* and *c*.
- Constituents were in original PM mix in percentages

p_a, p_b, p_c

- Set:

$$\beta_a = \frac{0.5\beta}{p_a} \quad \beta_b = \frac{0.5\beta}{p_b + p_c} \quad \beta_c = \frac{0.5\beta}{p_b + p_c}$$

- Then:

$$y = Be^{\beta_a x_a + \beta_b x_b + \beta_c x_c} = Be^{\frac{0.5\beta}{p_a} p_a x + \frac{0.5\beta}{p_b + p_c} p_b x + \frac{0.5\beta}{p_b + p_c} p_c x} = Be^{\beta x}$$

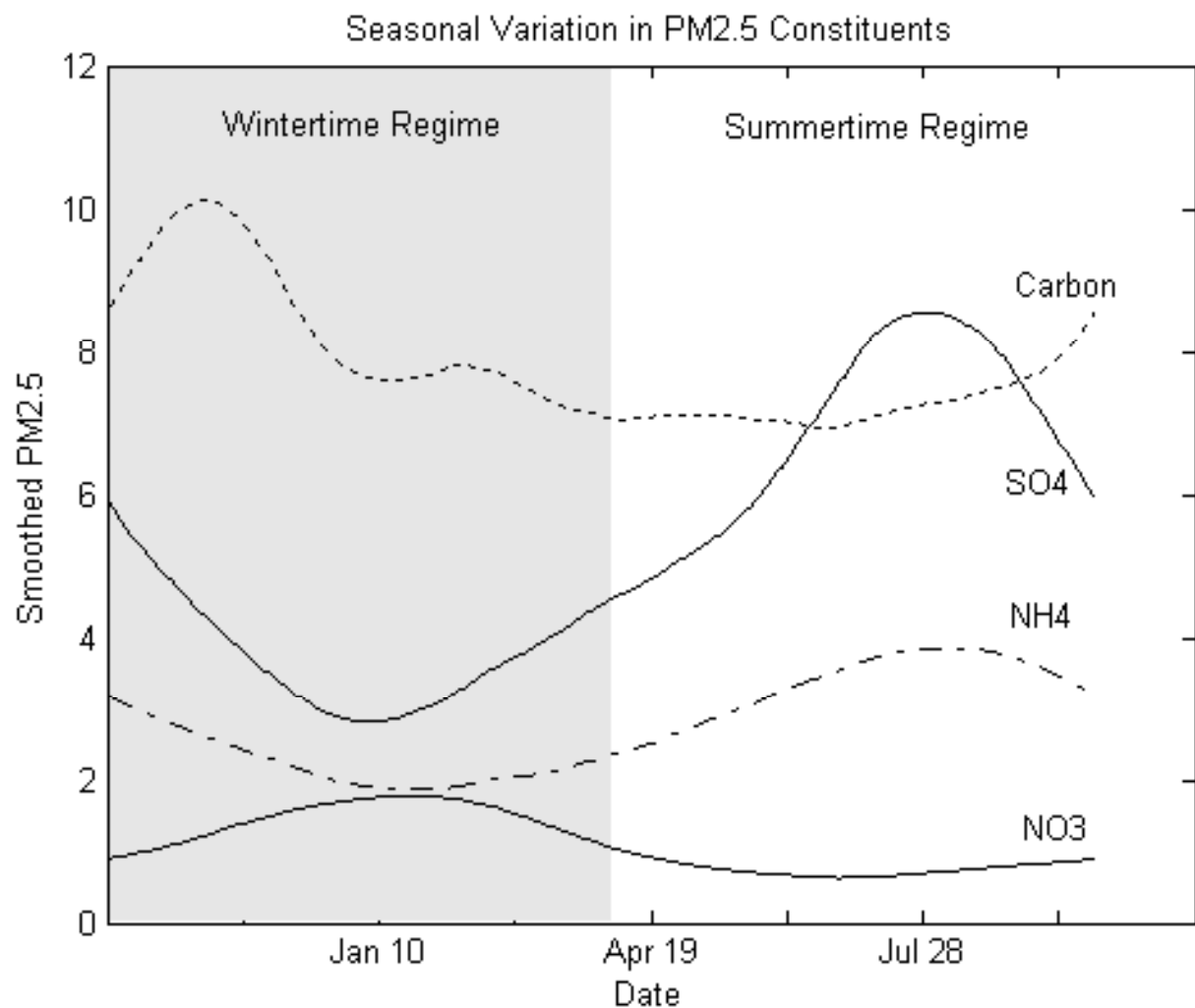
Pollutant Rollback Scenarios

- All emphasis to date has been on proportionality of rollback on individual days.
- Implementation strategies may reduce constituents in different proportions than the total % reduction.
 - ◆ Constituent-level rollback differences are more important to risk estimates
 - ◆ **But this cannot be demonstrated until potency differences are added, and the two risks are considered in combination.**
- Examples of rollback scenarios that we consider:
 - ◆ Reduce power plant emissions first, then others as nec.
 - ◆ Reduce local sources (autos) first, then regional as nec.

Application to Atlanta Data from SEARCH Project

- **Data from July 1998 to December 2001.**
- **Daily mass for many individual constituents.**
- **Developed stochastic relationships to allow simulation of multiple years using Monte Carlo.**
 - ◆ **Seasonality suggested two divisions**
 - ◆ **Individual constituents found to be lognormally distributed within each season.**
 - ◆ **Correlation structure preserved in sampling.**
 - ◆ **Ammonium mass predicted directly from SO₄ and NO₃ draws based on deterministic empirical relationship.**
 - ◆ **High R²**
 - ◆ **Coefficients consistent with expected chemistry**
 - ◆ **Coefficients highly significant**

Summary of Patterns in SEARCH Data



Monte Carlo Risk Analysis Based on SEARCH Data

- 100 years of PM_{2.5} daily concentrations generated.
- Each day has realistic but varying constituent mix.
 - ◆ sulfates
 - ◆ nitrates
 - ◆ organic matter
 - ◆ elemental carbon
 - ◆ crustals
 - ◆ ammonium
- Results that follow report risk estimates for minimum, maximum and mean over the 100 years.
- Used $B=100$, so results are all interpreted as indexed to a death rate of 100 -- i.e., “percentage impacts”

Chronic/Acute Risk and Threshold Sensitivities (Interactions)

Coefficient Values: $\beta_{\text{acute}} = 0.00148$, $\beta_{\text{chronic}} = 0.00671$ ***

(for all scenarios, simple rollback to target mean total = $15 \mu\text{g}/\text{m}^3$)

Values shown: (min, mean, max)

Units: percent change from baseline mortality

Model Type	Loglinear Coefficient	Threshold Choice		
		Without Threshold	Soft Threshold $12 \mu\text{g}/\text{m}^3$	Soft Threshold $18 \mu\text{g}/\text{m}^3$
Acute	β_{acute}	(0.9, 1.11, 1.33)	(0.8, 1.03, 1.37)	(0.65, 0.92, 1.48)
Chronic	β_{acute}	(0.9, 1.1, 1.32)	(0.66, 0.84, 1.04)	(0.38, 0.5, 0.65)
Chronic	β_{chronic}	(4.46, 5.49, 6.63)	(3.14, 4.02, 5.04)	(1.77, 2.35, 3.06)

*** We took these coefficient values from the two most commonly cited studies in PM risk analysis literature, without comment on their quality or appropriateness for future PM risk analyses

Relative Potency Cases Considered

(Toxicity of EC always set to 1.0)

Model	SO ₄	NO ₃	NH ₄	EC	OM	CRUSTAL	OTHER
Base	1	1	1	1	1	1	1
EC/OC 100% Impact	0	0	0	1	1	0	0
EC/OC 50% Impact	0.58	0.58	0.58	1	1	0.58	0.58
SO2 50% Impact	2.97	1	1	1	1	1	1

Interactions Between Differential Potency and Rollback Assumptions

Values shown: (min, mean, max) Units: percent change from baseline mortality

Rollback Scenarios	Acute Model Versions			
	EC/OC		Sox	
	Base	100% Impact	50% Impact	50% Impact
Plain Rollback	(0.91, 1.08, 1.26)	(0.89, 1.06, 1.24)	(0.91, 1.08, 1.26)	(0.89, 1.07, 1.25)
Power Plant Scenario: 70%	(0.90, 1.08, 1.26)	(0.00, 0.22, 0.47)	(0.72, 0.90, 1.09)	(1.30, 1.48, 1.65)
Mobile Source Scenario: 25%	(0.91, 1.08, 1.26)	(0.47, 0.51, 0.55)	(0.82, 0.96, 1.11)	(0.96, 1.18, 1.39)
Mobile Source Scenario: 50%	(0.90, 1.08, 1.26)	(0.95, 1.02, 1.10)	(0.92, 1.07, 1.22)	(0.84, 1.05, 1.26)
Mobile Source Scenario: 70%	(0.90, 1.08, 1.26)	(1.32, 1.43, 1.53)	(1.01, 1.15, 1.31)	(0.74, 0.95, 1.16)

Bottom Line

- No one epidemiological model structure is more valid than others on either scientific or statistical grounds.
- It is very unlikely that the basic mortality risk formula produces either correct or a “most likely” value.
- Seemingly minor model modifications affect risk estimates substantially.
- The way to better research and policy judgments entails exploring impacts of risk model extensions.
 - ♦ Singly and in combination.

Acceptance of broader uncertainty ranges will enable broader acceptance of the risk estimates themselves.



*Boston, Washington DC, Los Angeles,
Philadelphia, Berkeley, Palo Alto, Salt Lake City, Austin, Houston
London, Brussels, Toronto, Mexico City, Wellington, Brisbane, Melbourne*